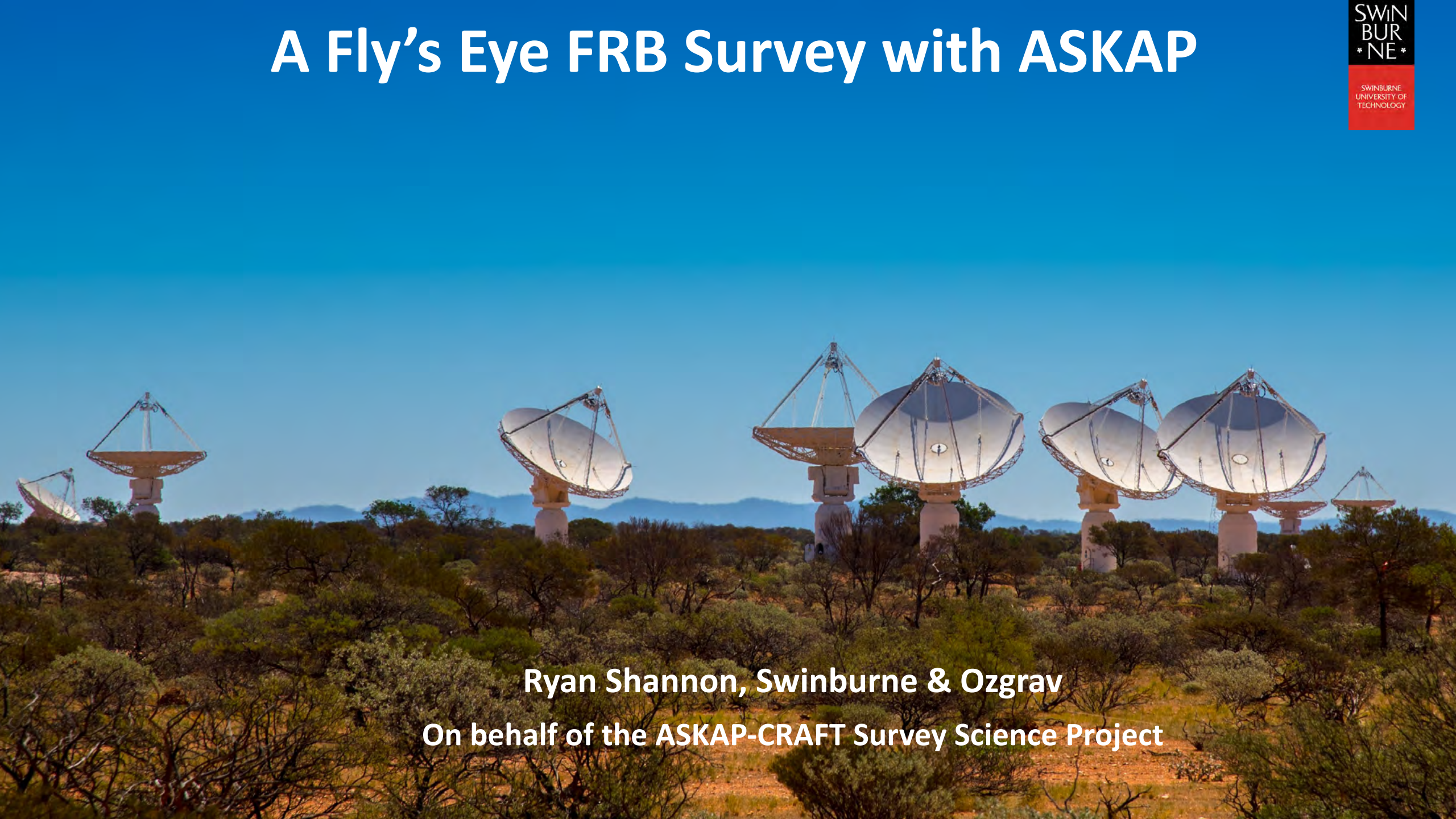
A Fly's Eye FRB Survey with ASKAP



Ryan Shannon, Swinburne & Ozgrav

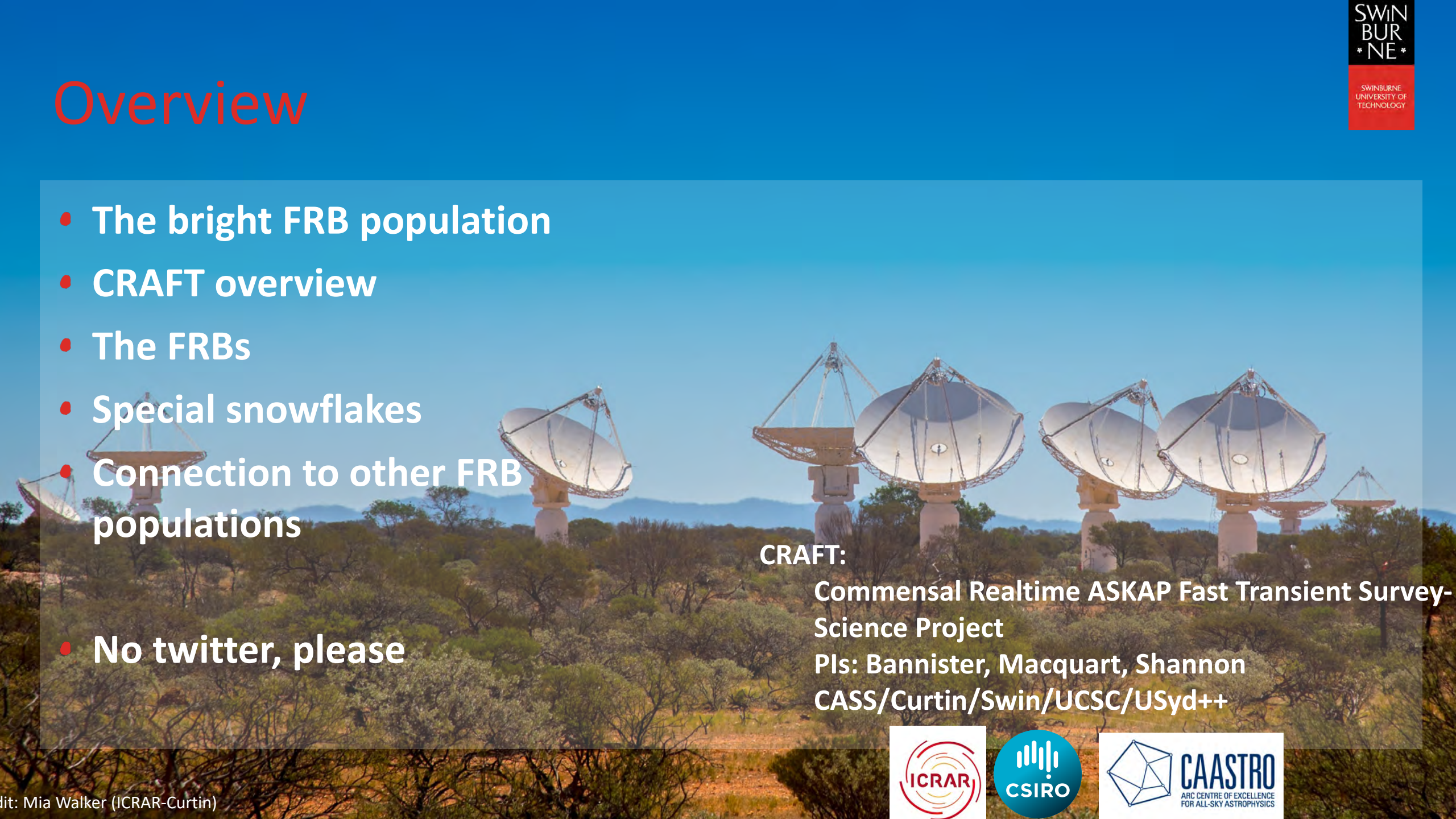
On behalf of the ASKAP-CRAFT Survey Science Project

Overview

- The bright FRB population
- CRAFT overview
- The FRBs
- Special snowflakes
- Connection to other FRB populations

- No twitter, please

CRAFT:
Commensal Realtime ASKAP Fast Transient Survey-Science Project
PIs: Bannister, Macquart, Shannon
CASS/Curtin/Swin/UCSC/USyd++

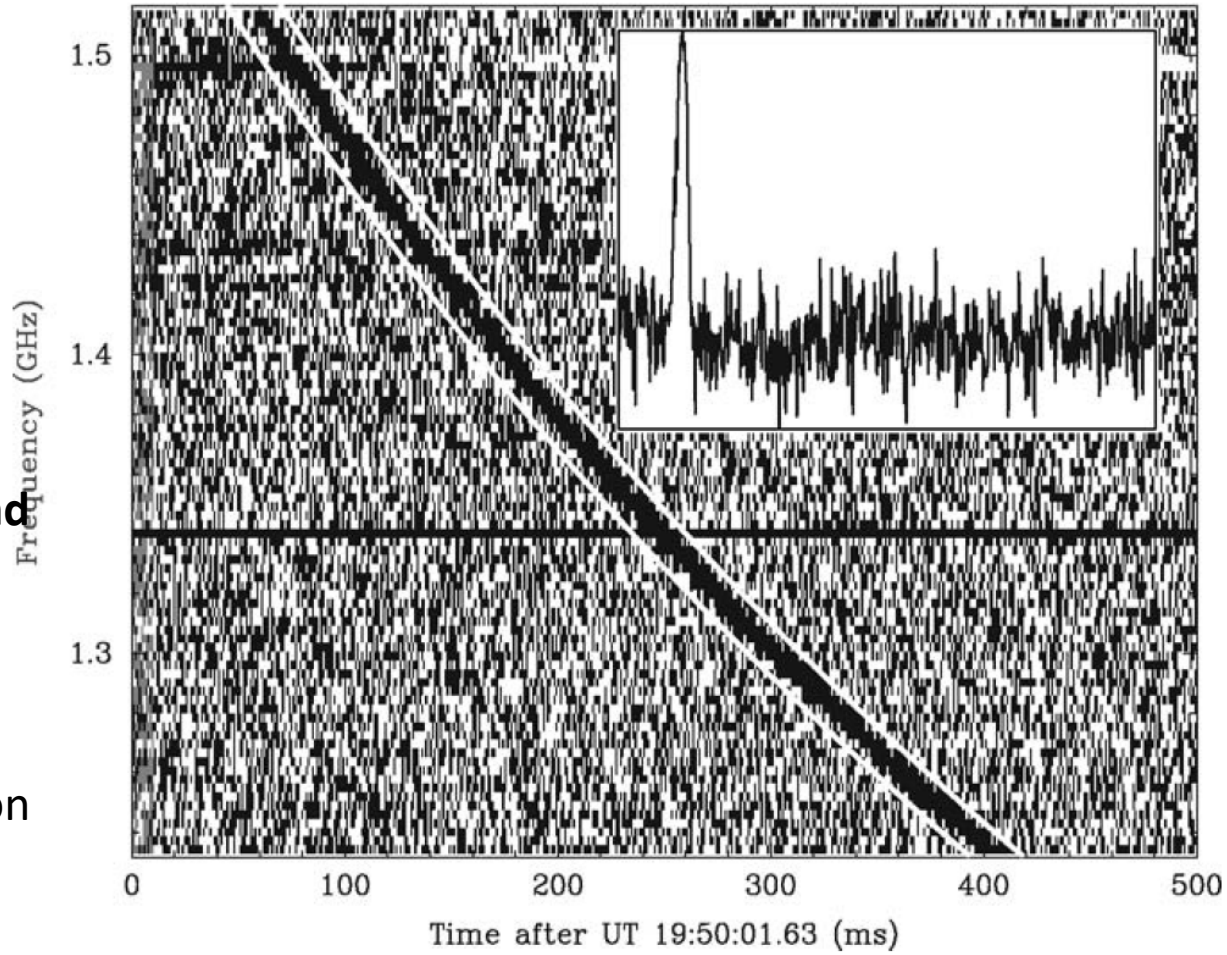


dit: Mia Walker (ICRAR-Curtin)

Fast Radio Bursts (FRBs)

- Highly dispersed, short, bright single pulses of radio emission
- Surprisingly frequent, but infrequently detected
  - 2000 – 6000 sky^{-1} day^{-1} above a fluence of ~ 2 Jy ms (Bhandari et al. 2018, Keane & Petroff, Champion)
  - 29 heretofore published: (22 Parkes, 5 UTMOST, 1 Arecibo, 1 Green Bank)
- **New unprecedentedly bright radio emission**
  - Cataclysmic explosions?
  - Germane pulsar emission?
- If cosmological, opportunity to **probe diffuse inter-cluster and intergalactic plasma**
  - Find missing baryons (via electrons)
  - Study its distribution and turbulence, feedback
  - With polarisation (rotation measure), study magnetisation of Universe

Lorimer et al. (2007)

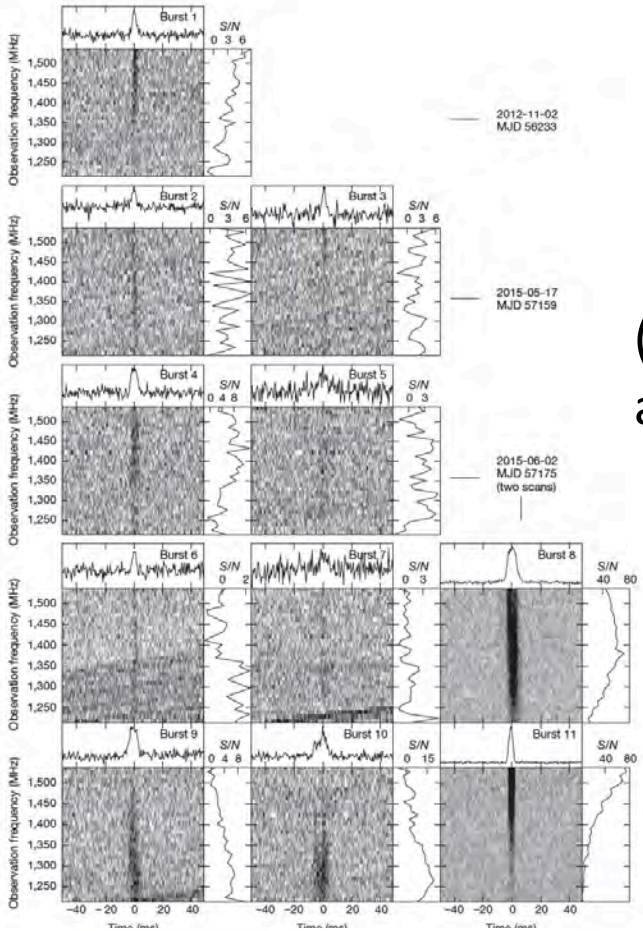


A repeating FRB

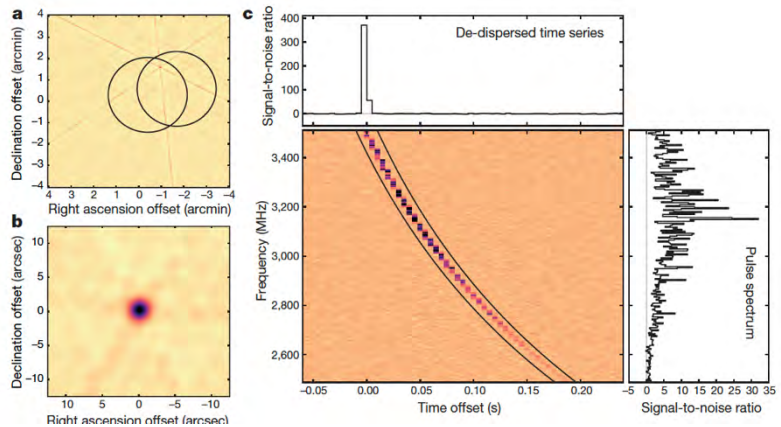
- Repeat bursts from the Arecibo FRB (121102)
- Wildly variable spectral index
- Pulses seen up to ~ 8 GHz (X-band)
- No obvious periodicity in the pulses
- Repetition enabled follow up with interferometers: JVLA and EVN
  - Source found in dwarf galaxy at z ~ 0.2 (Chatterjee et al. 2017)
  - Confirms cosmological distance scale
- Strange environment:
  - Radio nebulae, high rotation measure (Michilli et al. 2018), etc.

- **How does the repeater relate to the rest of the population?**

- **See Laura's talk for an update on the repeater**

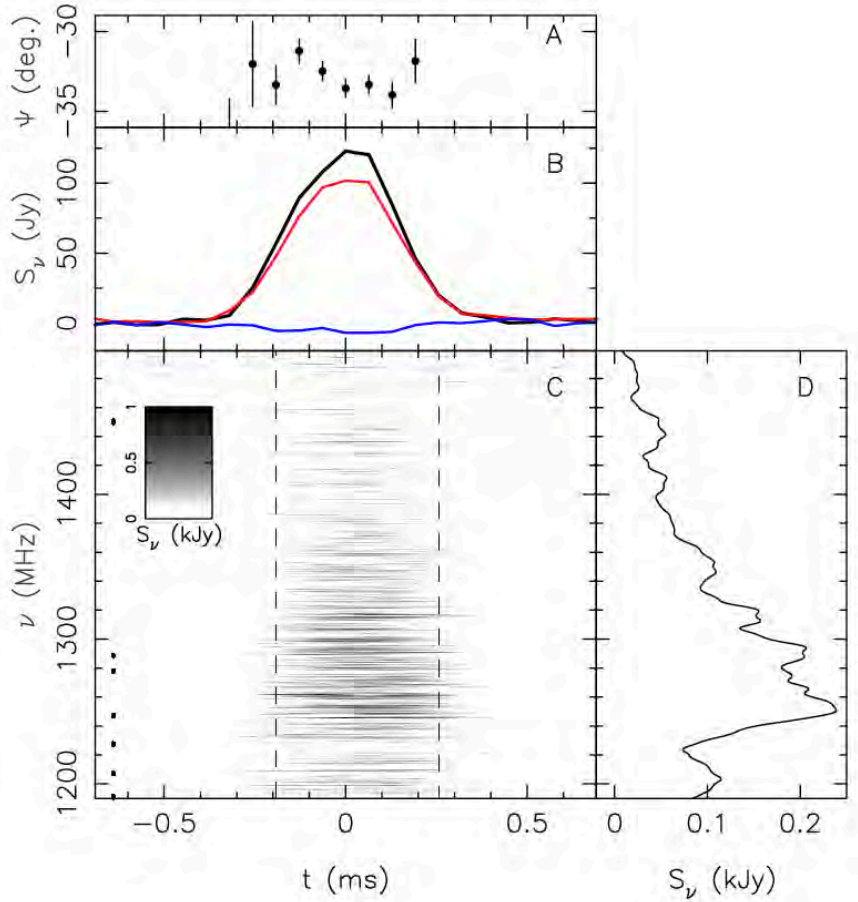


(Spitler et al. 2016)



Another super-bright FRB 150807

- Discovered at Parkes while timing millisecond pulsar
- **Low DM** (for FRB)
  - 265.5± 0.1 pc cm^{-3}
  - (Pulsar in field: 11 pc cm^{-3})
- **Bright: Detected in 2 beams**
  - Good localisation (for PKS)
  - Correct for attenuation: robust flux density estimate
- **Highly linearly polarized, little Faraday rotation**
  - Extragalactic <B> field < 10 nG
- No repeat in hundreds of hours of follow up observations
- Conclusion: bright FRBs aren't rare (Ravi et al., 2016)
- Further examples: UTMOST (Caleb et al, Farah et at.)



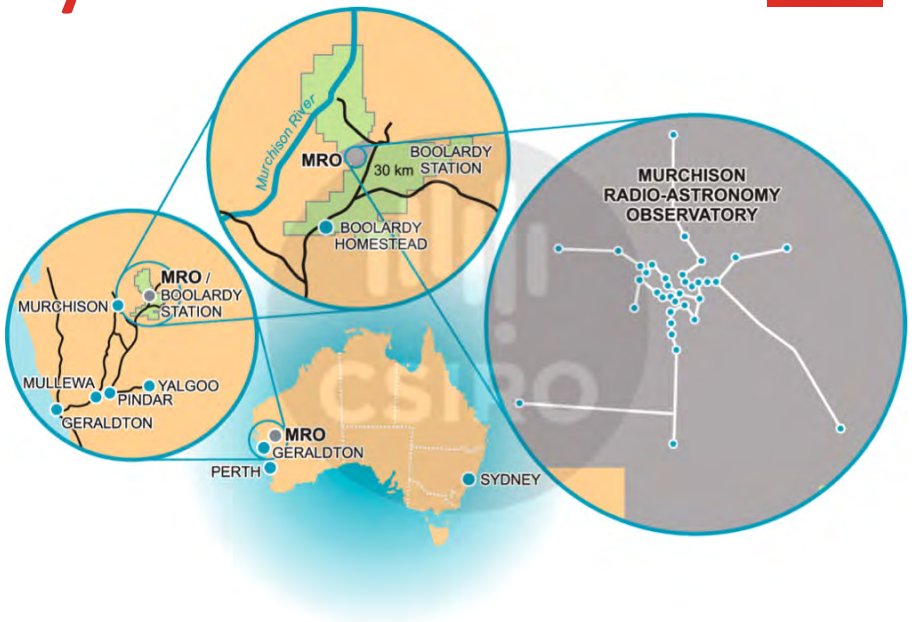
Bright FRBs exist: are they plentiful?

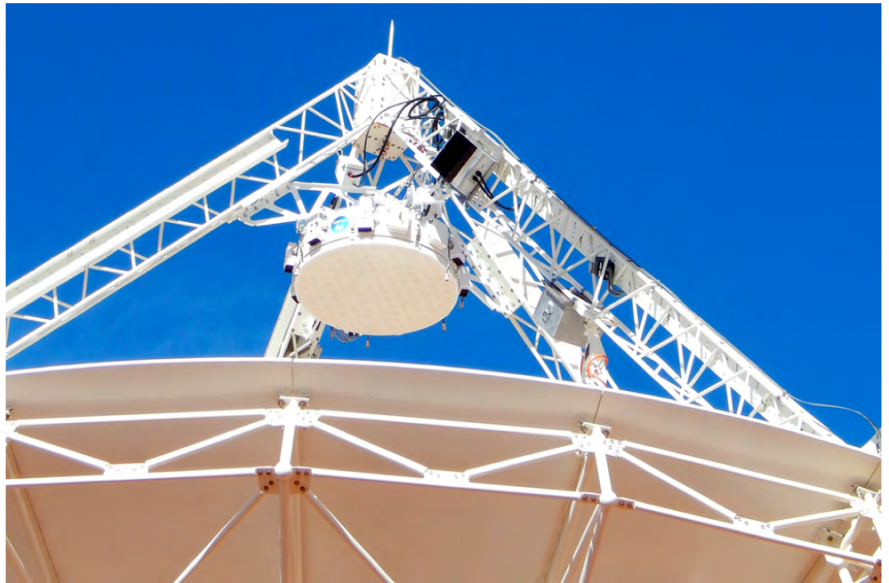
- Late 2015: Significant fraction of Parkes FRBs are bright
  - Lorimer burst: > 30 Jy ms
  - FRB 150807: 50(20) Jy ms (Ravi et al. 2016)
  - Flat source counts? (Vedantham et al. 2017)

- 10% of the Parkes population detectable by small wide field telescopes

Australian Square Kilometre Array Pathfinder

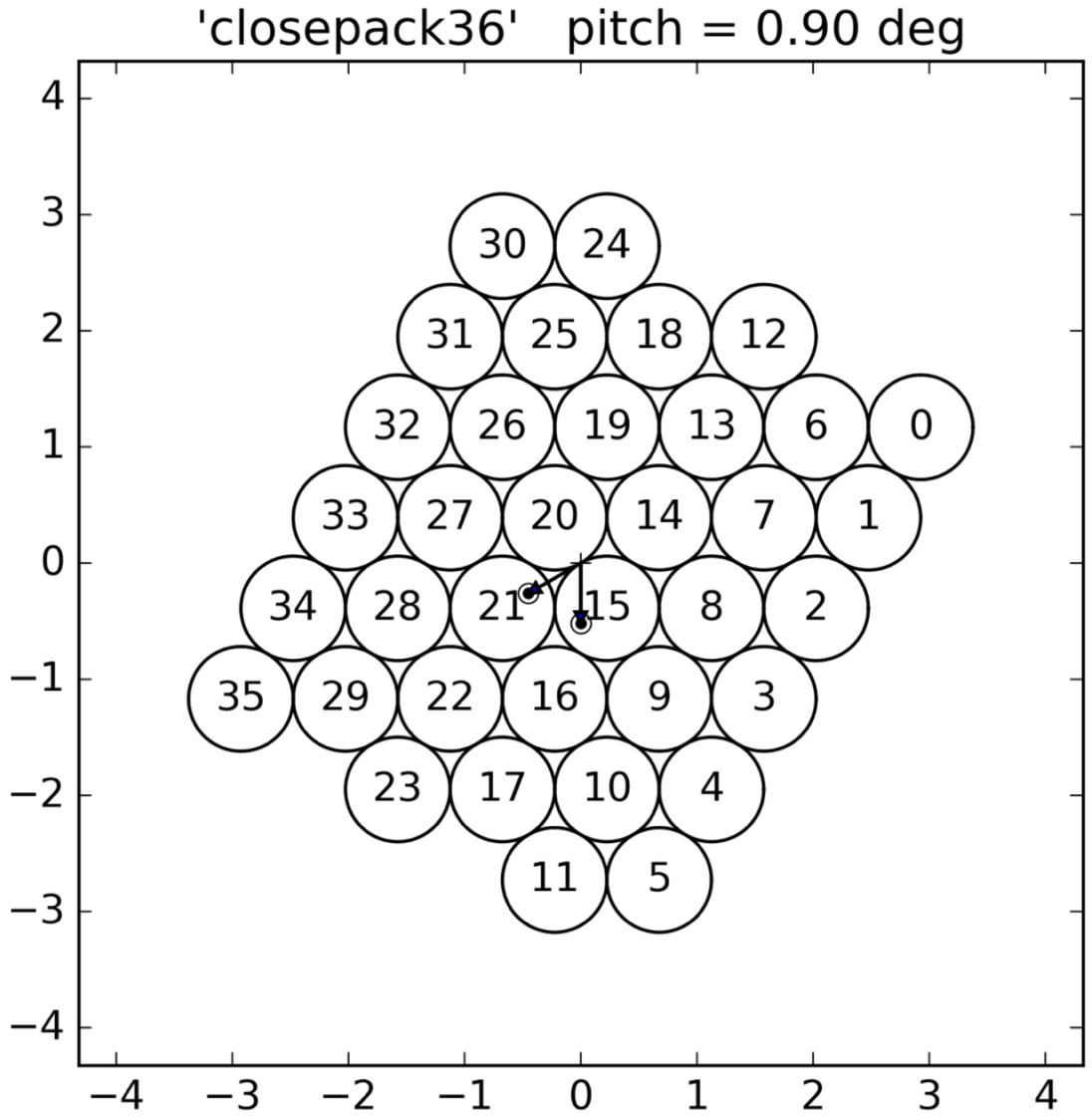
- Murchison Shire, Western Australia
- 36 x 12-metre antennas
- Focal plane arrays: 36 digital beams on the sky
- Each PAF: 30 deg^2 field of view
- 336 MHz available bandwidth
- Available frequency band: 0.7-1.8 GHz
- S_{sys}: 1800 Jy
- Signal path:
  - PAF (RfoF) -> Digital Receiver -> Beamformer -> ~~Correlator~~
- Dominant sources of interference: satellites, lightning (rare), ~~chirps~~ and ~~300 Hz~~.





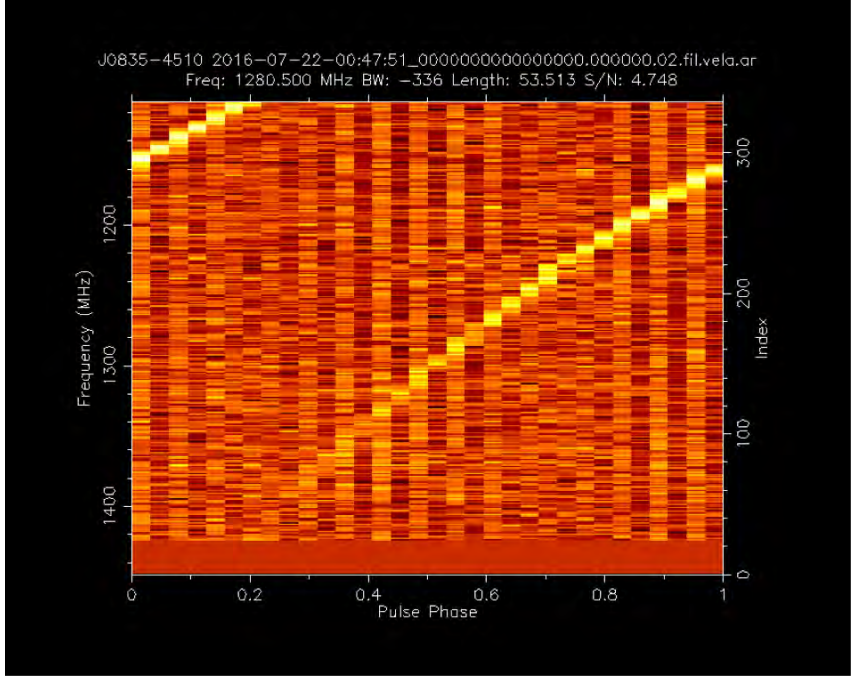
CRAFT mode/processing

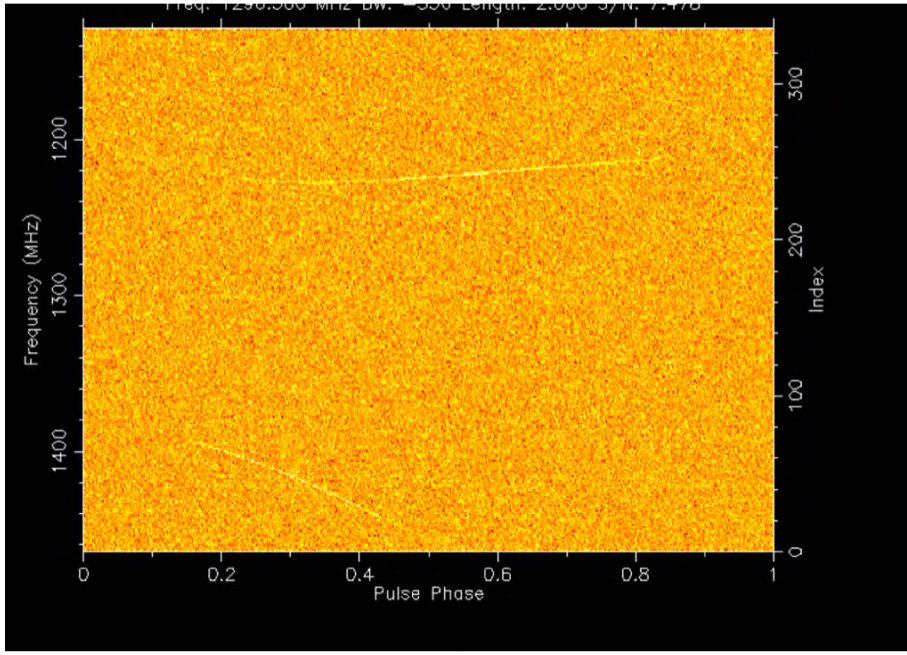
- Data products produced in beamformer:
  - After coarse channelization but before before narrow band channels (1 MHz resolution)
  - Detect and integrate data; sum both polarisations (1.26 ms)
- Data broadcast from beamformers over ethernet
- Captured by ingest machine
  - Current mode: scaled to 8-bit and written as sigpoc filterbank format
- Searched offline using “FREDDA” algorithm on ingest machines (mostly)/ Pawsey supercomputer (occasionally)
  - Current archive at Pawsey: 1 PB



Challenges with data sets

- Working with a telescope in commissioning phase
- Networking / packet drops
- 300 Hz
  - Cause: poor conditioning of power.
  - Solution: adjust transformer levels
- Chirps:
  - Impulsive interference (harmonics of lower frequency signal)
  - Cause: domino (PAF backplane) monitoring
  - Solution: turn off domino monitoring
- Data overflow:
  - Brightest signals were overflowing 8-bit samples



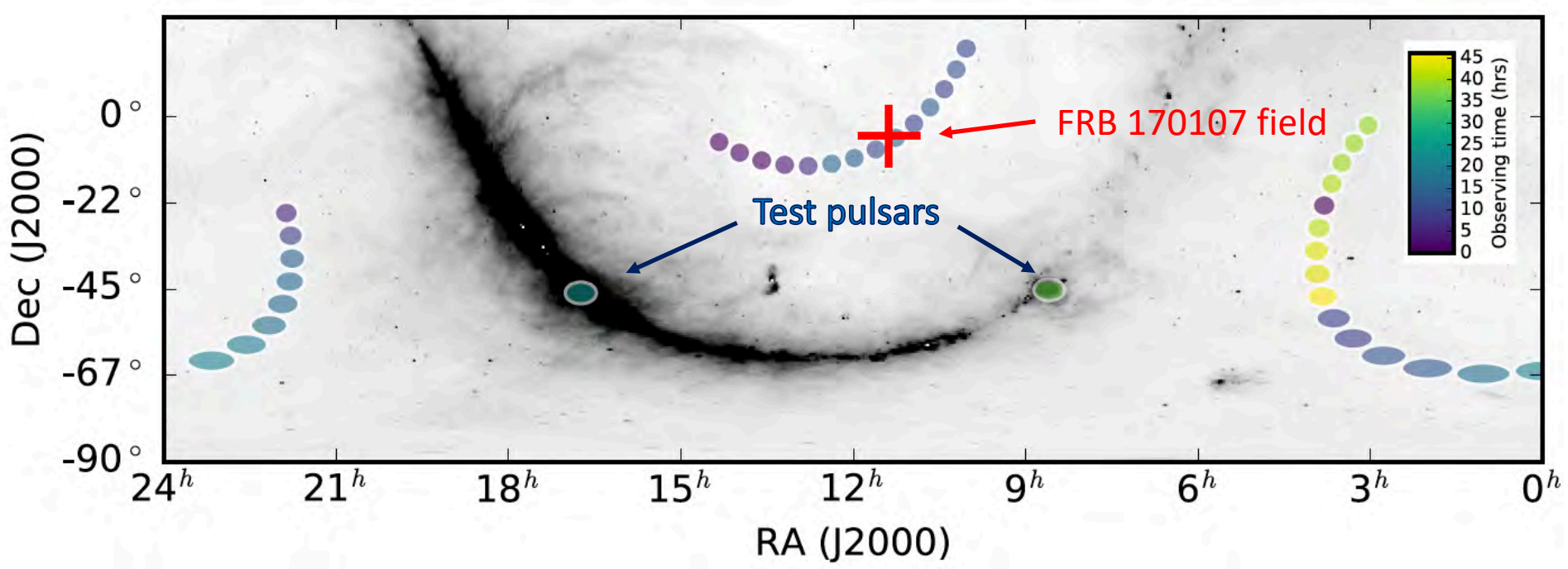


Fly's eye survey: Motivation

- ***Easy:* obvious first step for commissioning instrument**
- **Maximise field of view**
  - Pointing selection optimized for MWA co-observation (low zenith angle, close together, see Ramesh's talk)
- **Fixed, high Galactic latitude ($|b| = 50°$)**
  - Rates higher at high latitude? (Petroff et al, Macquart & Johnston)
  - Lower DM contribution from MW (30-40 pc cm^{-3})
  - 57 fields, 57 minutes per pointing: re-observe fields regularly
- **Central frequency of 1300 MHz**
  - Direct comparison to Parkes
- **Calibration:**
  - Digital beamforming done with Sun (beam weighs change from set to set)
  - For each set of beam weights, observe pulsar in all beams
  - Observe pulsar (Vela, B1641-45) at centre of a central beam (15)
  - See Clancy's talk for further discussions about beam efficiency

ASKAP detects its first FRB

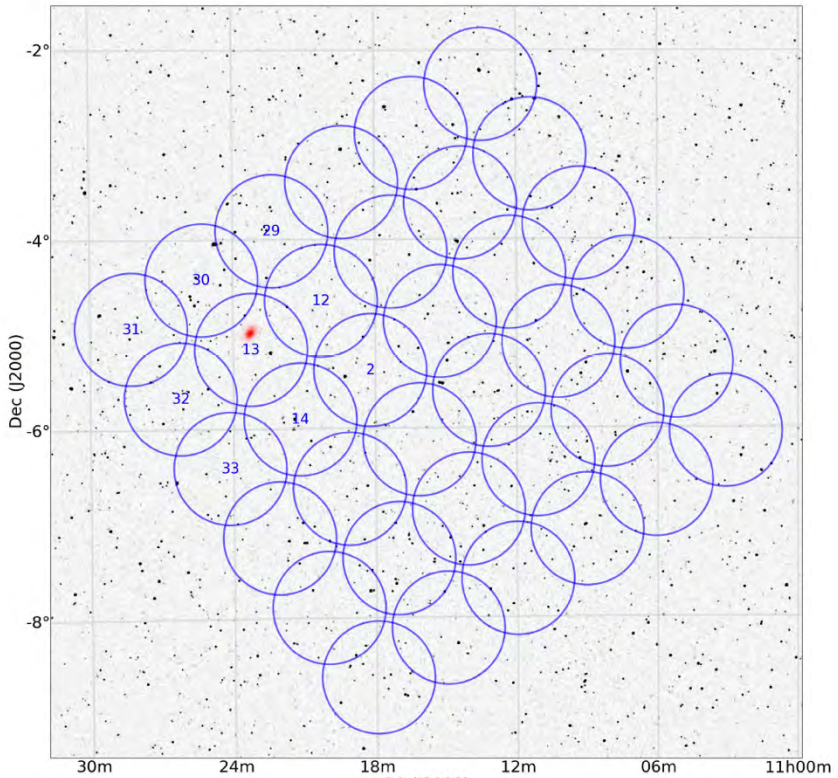
- Late 2016: new data capture modes finished
- First scientific observing run in January 2017: 6 antennas
- First FRB (170107; Bannister et al. 2017)

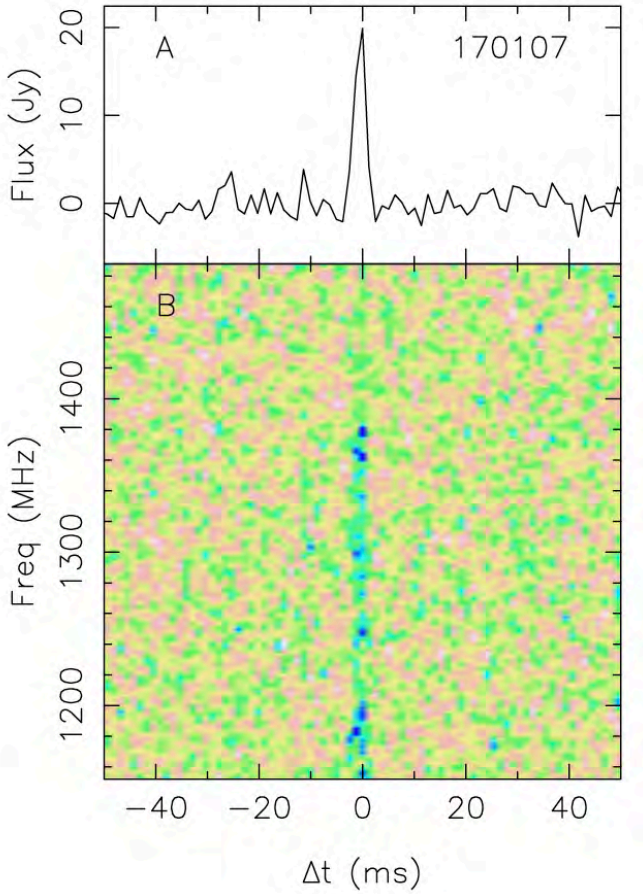


Backround: CHIpass map (Calabretta et al. 2014)

FRB 170107

- "Easy": detected FRB with 3.5 days of observing
- Dispersion measure: 609.5(5) pc cm^{-3}
- Peak flux density > 20 Jy
  - Confirms presence of population of bright FRBs
- Strong spectral cutoff





Pulse profile

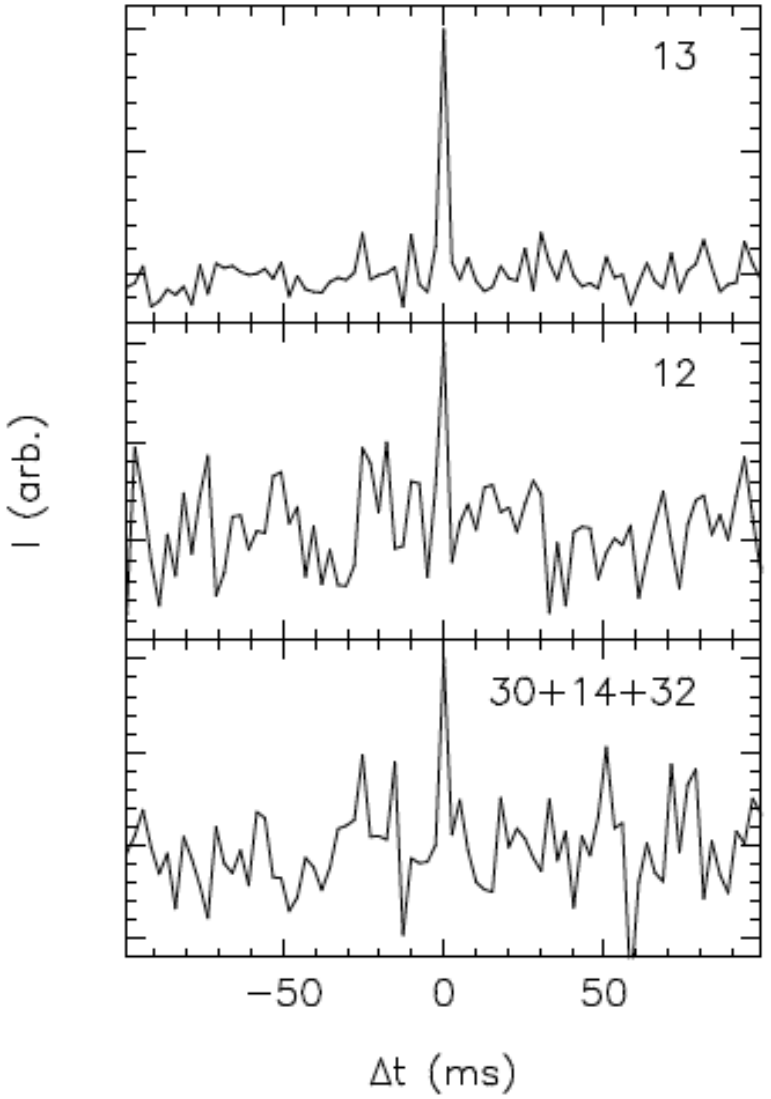
Pulse spectrum after de-dispersion

Background: NVSS map of galaxies
Blue: ASKAP pixels for one antenna
Red: region where FRB could be coming from

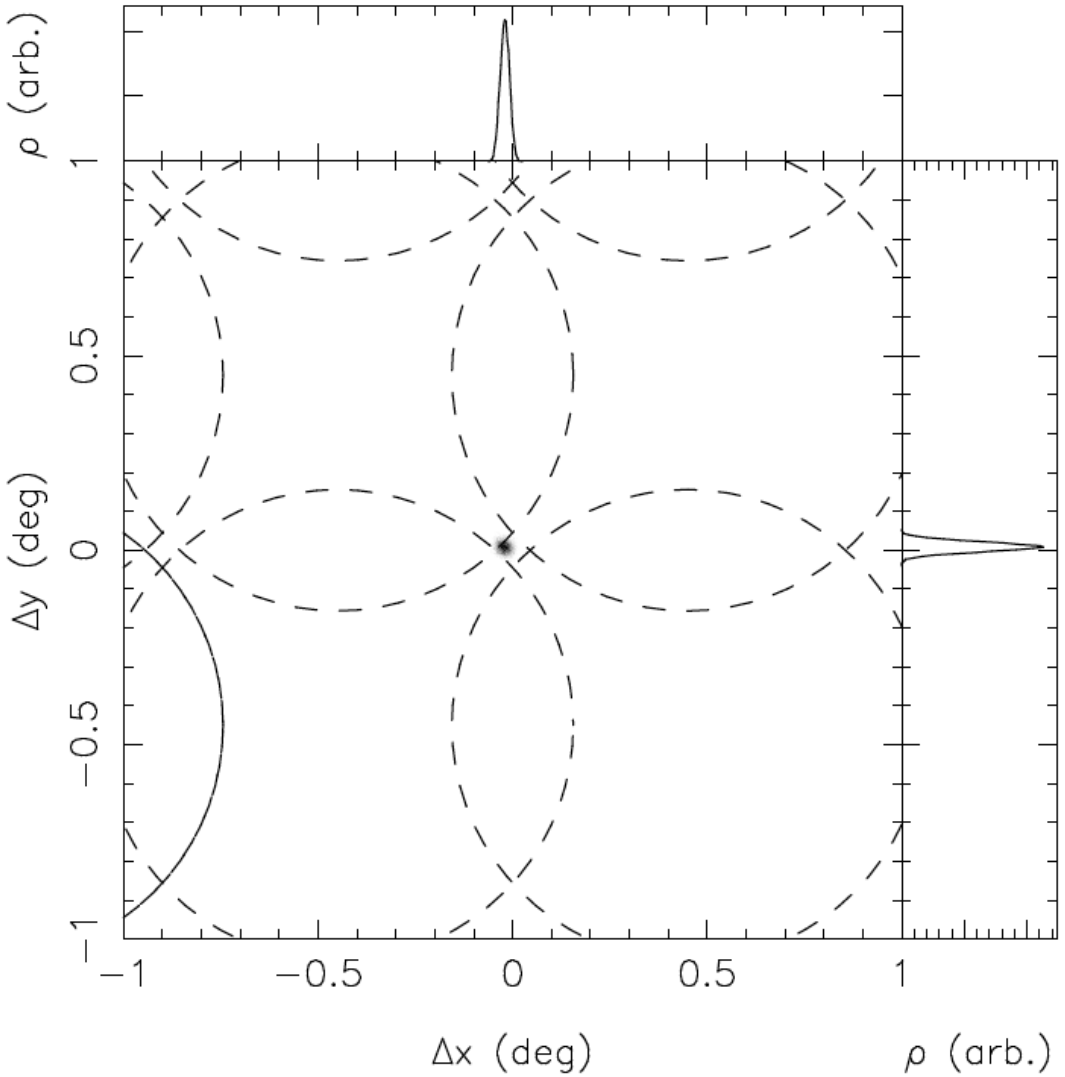
ASKAP localizations

- Overlapping beams: expect multiple detections
- Use detections (and non-detections) to determine localization of burst
  - Account for uncertainties in beam gain (sensitivity), width, and position
  - Bayesian search methods using `multinest` algorithm to sample posterior distribution
  - Achieve precision of ~ beam width/ (Signal-to-noise ratio) as expected

Burst profiles in different beams



Test: localizing a pulsar with the PAF



Observations of PSR B1641-45 taken with the PAF ~ 60 minutes before/after FRB 170107 was detected

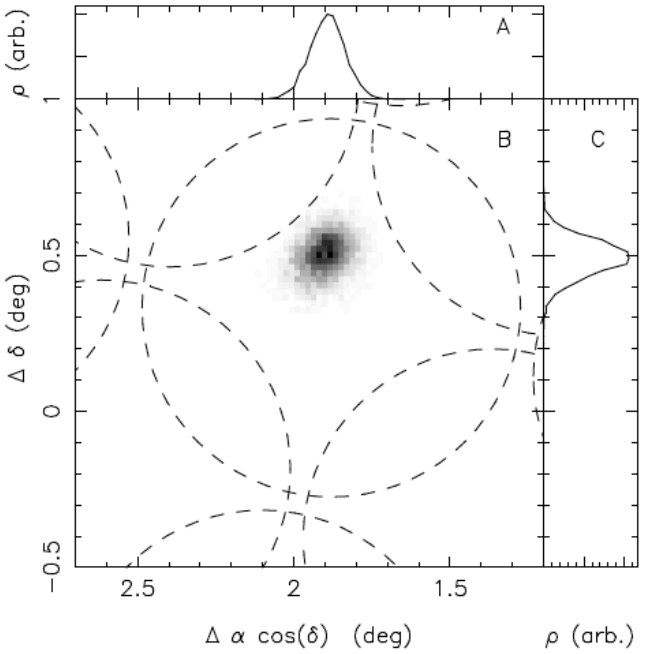
Expect pulsar to be at boresight (0,0) in PAF-centric coordinate system

Small ~0.6 arcmin offset, but pretty good, considering beam is > 120 arcmin in size at these frequencies

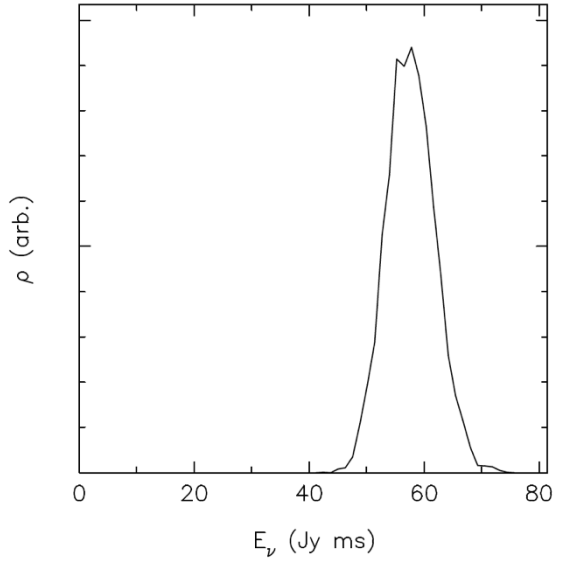
ASKAP fly's eye localizations

- Localize FRB to ~ 8x8 arcmin region (90% containment)
- Insufficient precision to identify unique host galaxy
  - Improvement over other single-dish measurements
  - Enables follow up with larger aperture facilities
- Strong constraints (upper and lower limits on burst fluence)
  - Important for constraining source brightness distribution and luminosity function

Posterior localization region



Posterior energy distribution



Future of CRAFT

- ASKAP-8 ->ASKAP36
  - Remaining digital systems on site this year
  - Detection rate will depend on access to antennas but will roughly proportional to N_{ant}
- Interferometric mode commissioning
  - Real time incoherent sum searches
    - Incoherent sum detection rate is $N_{ant}^{1/4}$ worse than fly's eye
  - Trigger voltage buffers
  - Off-line correlation
  - Enables localisation + polarimetry, coherent dedispersion
- See Keith's talk for overall plans